THE ANAEROBIC WASTEWATER TREAMENT OF PT. SARI HUSADA MILK INDUSTRY, YOGYAKARTA

Sindu Nuranto *)

ABSTRACT

Generally the objective of the biologically wastewater treatment is to remove the nonsettleable colloidal solids and to stabilize the organic materials. For industrial wastewater, the objective is to remove or reduce the concentration of impurities, i.e. organic and inorganic compounds. The anaerobic wastewater treatment process is an effective method to remove many organics materials in wastewater.

The milk industrial wastewater include PT. Sari Husada is composed form high concentration of organic materials like proteins, carbohydrates, fats, greases etc. Therefore the wastewater treatment require that anaerobic processes be applied subsequently. The method used is Upflow Anaerobic Sludge Blanket (UASB) to product more sludge in the retention time.

The anaerobic tank of PT. Sari Husada has a low efficiency, e.i. 54.86 %. , *caused by the shorter hydraulics retention time which is only 3.1 days, in fact the minimum is 8 days. The other factor are high temperature which more than 35° C. and alkalinity or pH range which more fluctuatively.*

Anaerobic tretment of industrial wastewater like textile, paper, food and milk, sugar etc., has become an interisting alternative for the removal of waterpollution.

INTRODUCTION

Background

PT. Sari Husada Yogyakarta locate in Gajah Wong River Basin, so the wastewater throwed away to this river. Actually PT. Sari Husada Yogyakarta products the waste which consist of three forms i.e. solid waste, wastewater and gas. The wastewater is potensial waste to pollute the environment, especially the Gajah Wong River, but PT. Sari Husada treats them to remove or reduce the impurities which orientate to the wastewater quality standard.

The wastewater has high BOD (biochemical oxygen demand), COD (chemical oxygen demand) and TOC (total oxygen carbon), because there is high concentration of organic materials. Organic materials or biodegradable organics are composed pricipally of proteins, carbohydrates and fats. Biodegradable organics are measured most commonly in term of BOD, COD and TOC.

Objective of the study

The objective of the study is to evaluate aerobic and anaerobic processes in the PT. Sari Husada wastewater treatment plant and to propose alternative solution to increase the efficiency.

LITERATURE REVIEW

Wastewater Characteristics

Industrial wastewater is that which is discharged from manufacturing plants like textile, pharmaceutical, chemical industry, pulp and paper, food and milk, sugar etc. Untreated industrial wastewater has many undesirable components, that are composed of both organic and inorganic materials. The characterization of a wastewater is an important to know before process selection and design is decided (Benefield and Randall, 1980).

The organic components of wastewater are composed of many different carbonaceous componds. The most common test for the organic content of wastewater are BOD, COD and TOC.

Decomposition of waste

The type of decomposition especially aerobic and anaerobic used by a mixed culture of microorganicms. The aerobic decomposition for bacterial metabolism that molecular oxygen (O_2) must be present for decomposition to proceed by aerobic oxydation. The chemical end products of decomposition are primarily carbon dioxide, water and new cell.

Aerobic decomposition is the method of choice for large quantities of dilute wastewater because decomposition is rapid, efficient and has a low odor potensial.

For high strength wastewater (BOD is greater than 1.000 mg/l) it is not suitable to use the aerobic treatment, because of the difficulty in supplying enough oxygen and because of the large amount of biological sludge that is produced. In order to anaerobic decomposition, molecular oxygen and nitrate must not be present as terminal electron

*) Ir. Sindu Nuranto, MS., Lecture at Department of Civil Engineering, Gadjah Mada University

acceptors. The result of anaerobic decomposition (fermentation) are carbon dioxide, methane and water is the major end product.

Additional end product include ammonia, hydrogen sulfide and methane. For BOD concentrated waste greater than 1.000 mg/l anaerobic digestion is quite appropriate.

MATERIALS AND METHOD

The capacity of anaerobic tank of PT. Sari Husada wastewater treatment plant is 650 m^3, that is 10 m length, 10 m wide and 7 m depth. The waste sample is took at inlet and outlet of the tank to test of many parameters that are temperature, pH, COD and wastewater flowrate.

The BOD test gives a measure of the oxygen used by microorganism especially bacteria during the oxidation of organic material contained in a wastewater sample. The test is based on the premise that all the biodegradable organic material contained in the wastewater sample will be oxidized to CO_2 and H_2O by microorganism using molecular oxygen (Davis M. L. and Cornwell D. A., 1991).

The COD test is used to determine the oxygen equivalent of the organic material that can be oxidized by a strong chemical oxidizing agent (potassium dichromat) in an acid medium. The COD test is based on the principal that most organic compounds are oxidized to CO_2 and H_2O by strong oxidizing agents under acid conditions.

Generally, the COD of waste will be greater than the BOD_5 because more compounds can be oxidized chemically than can be oxidized biologically, and because BOD_5 does not equal ultimate BOD. In practice to measure that standard BOD at 5 days, this mean to minimise the effect to nitrification.

The total carbon (TOC) analyzer allows a total soluble carbon analysis to be made directly on an aqueous sample. In many cases TOC measurements can be correlated with COD and aceasionally with BOD values, becase the time required for carbon analysis is generally short (a few minutes), such correlations are extremely helpful when monitoring treatment plant flows for efficiency control.

THEORETICAL BASIS

The anaerobic wastewater treatment resulting in the production of methane and carbon dioxide, can used the conventional digester and the two-stage high-rate process. The conventional digester is one tank to which fresh feed is added either continuously or several times a day. All the process like gas, digestion, evolution, sludge thickening and supernatant formation work in the same tank, so it is needed the depth layer. The two-stage process is used to separate the digester layer into another tank.

McCarty (1968) in Benefield, L. D. and Randall, C. W. (1980) reported that only one group of methane bacteria is necessary of the methane fermentation of acetic acid. Whereas propionic acid, which fermented through acetic acid, requires two differents group of methane bacteria.

The methane fermentation reaction for acetic acid is given by equation 1, and the propionic acid is given by equation 2, 3, and 4.

Acetic acid :

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (1)$$

Propionic acid:

First step:

$$CH_3CH_2COOH + 0.5H_2O \rightarrow CH_3COOH + 0.25CO_2 + 0.75CH_4 \quad (2)$$

Second step:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (3)$$

Overall:

$$CH_3CH_2COOH + 0.5H_2O \rightarrow 1.25CO_2 + 1.75CH_4 \quad (4)$$

The conventional anaerobic digester is used to treat the PT. Sari Husada wastewater, which is completely fixed reactor without recycle. The schematic of the anaerobic wastewater process is shown in Figure 1 and the schemathic of completely mixed reactor without recycle is presented in Figure 2.

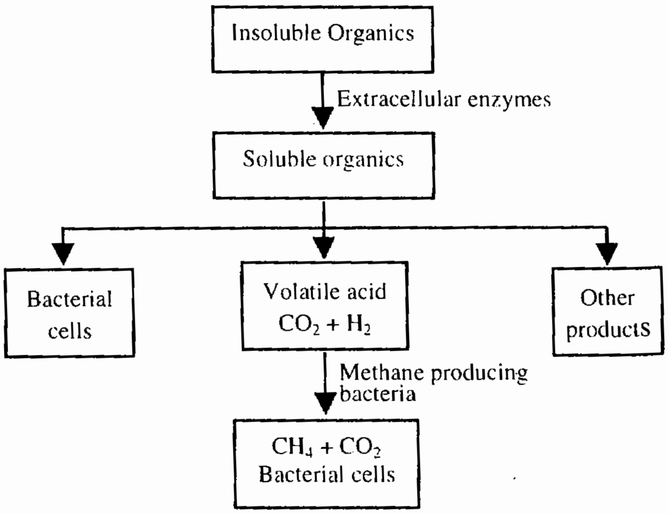

Figure 1. Sequential mechanism of anaerobic wastewater process. (After Andrews, 1975 in Benefield, L. D. and Randall, C. W., 1980)

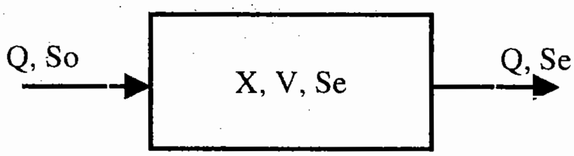

Figure 2. Schematic of Completely Mixed Reactor without solids recycling. (Benefield, L. D. and Randall, C. W., 1980)

From the figure 2 Q is the wastewater flowrate (m^3/day), So is the influent substrate concentration (mg/l), X is the steady-state biomass concentration (mg/l), V is the reactor volume (m^3) and Se is the effluent substrate concentration (mg/l).

A material balance for substrate entering and leaving the reactor can be written in Equation (5).

$$\begin{bmatrix}\text{net rate of change}\\ \text{in amount of substrate}\\ \text{within anaerobic tank}\end{bmatrix} = \begin{bmatrix}\text{rate at which}\\ \text{substrate enters}\\ \text{anaerobic tank}\end{bmatrix} - \begin{bmatrix}\text{rate at which}\\ \text{substrate disappears}\\ \text{from anaerobic tank}\end{bmatrix} \quad (5)$$

The Equation (5) can be expressed in Equation (6).

$$\left(\frac{dS}{dt}\right)Va = Q.So - \left(\frac{dS}{dt}\right)_u Va - Q.Se \quad (6)$$

At steady-state that rate at which substrate enters anaerobic tank is the same as rate at which substrate disappears from anaerobic tank, so it can be written in Equation (7).

$$\left(\frac{dS}{dt}\right)Va = 0 \quad (7)$$

Therefore, using the Equation (7), the Equation (6) reduces to Equation (8). .

$$\left(\frac{dS}{dt}\right)_u = \frac{Q.(So - Se)}{Va} \quad (8)$$

From the Figure 2, assuming no biomass in influent, a steady-state material-balance equation for biomasscan be written in Equation (9).

$$0 = \left[Y_T\left(\frac{dS}{dt}\right)_u - Kd.X\right]V - Q.X \quad (9)$$

Substituting from Equation (8) to Equation (9) gives the Equation (10) or Equation (11).

$$0 = \left[\frac{Y_T.Q.(So - Se)}{V} - Kd.X\right]V - Q.X \quad (10)$$

$$\frac{Kd.X.V}{Q} = Y_T.(So - Se) - X \quad (11)$$

or

$$X = \frac{Y_T.(So - Se)}{1 + Kd.\theta_c} \quad (12)$$

According to Lawrence and McCarty (1970) in Benefield, L. D. and Randall, C. W. (1980) that there is relation of the rate of substrate utilization to the concentration of microorganisms in the reactor and to the concentration of substrate surrounding the organism as given in Equation (13).

$$\left(\frac{dS}{dt}\right)_u = \frac{k.X.S}{Ks + S} \quad (13)$$

Substituting the Equation (13) to Equation (9) gives the Equation (14) and (15).

$$\frac{1}{\theta_c} = Y_T.\frac{k.Se}{Ks + Se} - Kd \quad (14)$$

$$Se = \frac{(1 + Kd.\theta_c).Ks}{\theta_c.(Y_T.k - Kd) - 1} \quad (15)$$

where:

θ_c = biological solids retention time, defined as the average time a unit of organic material remains in the treatment systems, day

Y_T = true growth yield

Se = the steady-state organic material concentration after treatment (measured as BOD), mg/l

Ks = saturation constant which has a value equal to the substrate concentration when (dS/dt)u/X = 1/2k, mass volume^{-1}

Kd = specific growth rate constant, day^{-1}

k = maximum specific substrate utilization rate, that is, the maximum rate of substrate utilization per unit of organic material, day^{-1}

If the rate of substrate utilization follows the Monod relationship, the critical biological solids retention time (θ_c^m) is given in Equation (16).

$$\frac{1}{\theta_c^m} = Y_T.\left(\frac{k.So}{Ks + So}\right) - Kd \quad (16)$$

where:

θ_c^m = the minimum biological solids retention time, day.

The minimum biological sludge retention time is reached when Se = So. McCarty (1968) in Benefield, L. D. and Randall, C. W. (1980) notes that Kd is small and can generally be neglected with little error. The minimum biological sludge retention time can be estimate by the equation (17).

$$\theta_c^m = \frac{1}{Y_T.k}.(\frac{Ks + So}{So}) \quad (17)$$

Lawrence and McCarty (1969) in Benefield, L. D. and Randall, C. W. (1980) state that when So > Ks, the θ_c^m value is given by the reciprocal of the maximum specific growth rate and designated as $(\theta_c^m)_{lim}$ is given by equation (18).

$$(\theta_c^m)_{\lim} = \frac{1}{\mu_{\max}} \approx \frac{1}{Y_T.k} \quad (18)$$

where μmax is maximum specific growth rate of nitrifying bacteria (day^{-1}). O'Rourke (1968) in Benefield, L.D. and Randall, C.W. (1980) propose that equation (15) can be modified into the equation (19).

$$(Se)_{overall} = \frac{1 + Kd.\theta}{\theta.(Y_T.k - Kd) - 1}.(Kc) \quad (19)$$

where Kc = Σ Ks for all fatty acids found or producted in the waste to be treated. He gives the impirical equation to define the effects of temperature on methane fermentation by equation (20) and (21).

$$(k)_T = (6.67\ day^{-1}).10^{-0.015(35 - T)} \quad (20)$$

$$(Kc)_T = (2224\ mg\ COD/l).10^{0.046(35 - T)} \quad (21)$$

RESULTS AND DISCUSSION

The results obtained from the research are given in Table 1.

Table 1. Daily report of anaerobic tank of PT. Sari Husada wastewater treatment plant

Daynumber	Temperature (°C)		pH		Flowrate (m^3/day)	COD (mg/l)	
	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet
1	46.83	45.4	8.00	7.5	120	4,560.60	1,880.40
2	45.67	44.5	7.42	6.75	220	5,242.60	2,130.40
3	45.00	42.7	7.42	7.5	nd	3,253.80	2,255.50
4	45.00	43.3	7.33	6.9	264.9	4,339.60	2,042.20
5	44.33	43	7.00	7.2	239	3,967.30	2,036.80
6	45.50	42.6	7.17	6.8	164	4,387.50	1,929.10
7	46.00	43	9.33	7	182	4,551.70	1,645.90
8	46.33	43.2	6.67	6.9	313.9	4,663.60	1,498.40
9	45.83	43.5	7.42	6.8	204.4	4,389.10	1,991.30
10	46.17	42	6.67	6.9	236.1	3,942.10	1,585.10
11	46.50	44	6.38	7	259	3,285.20	1,981.20
12	46.67	43.3	6.17	6.9	263.8	2,560.30	1,671.50
13	45.67	42.8	6.67	6.9	251	4,815.80	1,991.30
14	46.00	42.2	6.50	6.75	191.5	4,470.40	1,666.20
15	46.17	45	6.50	7.2	237.6	3,987.00	2,418.10
16	43.67	44.5	8.00	7	206.7	3,987.00	2,418.00
17	45.83	43.6	7.83	7.2	223.2	4,267.20	1,727.20
18	44.33	41.5	6.58	6.75	221.7	3,830.30	2,017.70
19	42.17	43.2	6.75	7.2	208.7	3,535.70	1,385.10
20	45.67	43.2	6.58	6.9	205.9	3,271.50	1,473.20
21	45.50	42	6.17	7	127	4,117.80	1,768.80
22	45.33	43.8	7.42	6.6	197.2	3,962.40	1,615.40
23	43.17	43.5	6.67	6.9	186	4,832.90	1,996.30
24	43.67	43	7.58	7	206	3,230.90	1,952.60
25	46.17	45	6.83	6.75	141	3,637.30	1,402.00
26	47.50	44.3	6.50	7.4	78.9	4,734.50	1,661.10
27	45.83	43.7	6.33	6.9	214	5,212.00	1,818.60
28	46.00	43.8	6.75	7	202	5,273.00	1,574.80
29	43.00	43.1	6.58	7	287.9	5,276.90	2,037.40
30	44.33	42.5	5.67	6.75	290.8	5,403.40	2,231.80
Total	1359.83	1301.20	208.88	209.35	6144.20	126,989.40	55,803.40
Average	45.33	43.37	6.96	6.98	211.87	4,232.98	1,860.11

Note: nd = not detected, there is an equipment repearing.
Source = PT. Sari Husada Yogyakarta wastewater treatment plant.

From the Table 1 show that:

$$COD_{(in)average} = 4{,}232.98 \text{ mg/l}$$

$$COD_{(out)average} = 1{,}860.11 \text{ mg/l}$$

$$T_{(in)average} = 45.33° \text{ C}$$

$$T_{(out)average} = 43.37° \text{ C}$$

$$pH_{(in)average} = 6.96$$

$$pH_{(out)average} = 6.98$$

$$Q_{average} = 211.87 \text{ m}^3\text{/day}$$

The alteration of COD, temperature and pH values of the wastewater throught the anaerobic tank for a month given in Figure 3, Figure 4 and Figure 5. The wastewater flowrate daily is given in Figure 6.

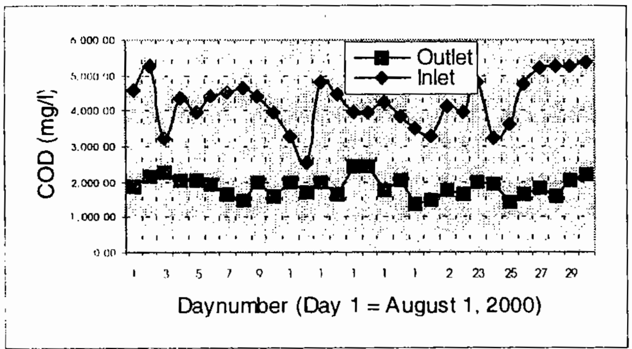

Figure 3. COD removal at the anaerobic tank for a month.

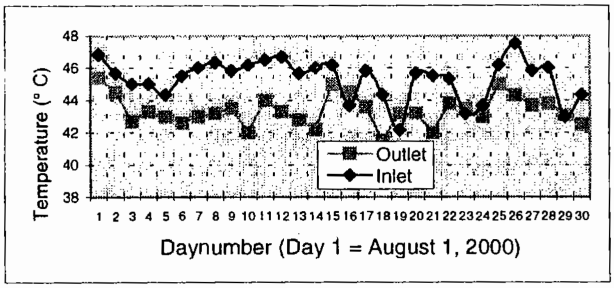

Figure 4. Temperature removal at the anaerobic tank for a month.

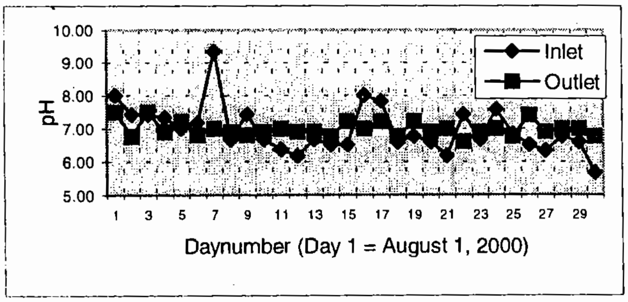

Figure 5. pH alteration at the anaerobic tank for a month.

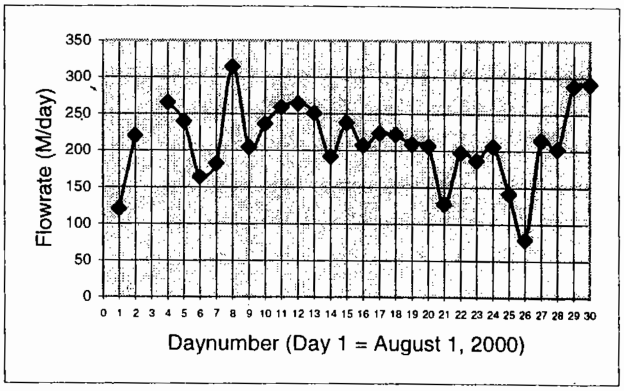

Figure 6. Wastewater flowrate

The equations (12), (13) and (14) are applicable for the wastewater temperature range 20° C to 35° C. To compute θ_c^m we can use equation (12) or the Table 2 which given by McCarty (1964) in Reynolds, T.D. (1982)

Table 2. Suggested values of the minimum mean cell residence time θ_c^m

Number	Operating Temperature °C	θ_c^m (days)
1	18	11
2	24	8
3	30	6
4	35	4
5	40	4

Source: After McCarty, P. L. (1964) in Reynolds, T. D.(1982).

The wastewater temperature average in the anaerobic tank is 45.33° C more than 40° C, so from the Table 2 we get $\theta_c^m = 4$ days.

The true growth yield (Y_T) and the specific growth rate constant (Kd) determined by Lawrence (1971) in Benefield, L.D. and Randall, C.W. (1980), observed little variation in the values with temperature are presented in Table 3.

Table 3. Range and average values of Y_T and Kd

Number	Parameter	Range	Average
1	Y_T (mg/mg)	0.040 - 0.054	0.044
2	Kd (day^{-1})	0.010 – 0.040	0.019

Source: After Lawrence (1971) in Benefield, L. D. and Randall, C. W. (1980).

Lawrence (1971) in Benefield, L. D. and Randall, C. W. (1980) suggest that for design purpose Y_T and

Kd, that $Y_T = 0.04$ and $Kd = 0.015$ are applicable for high-lipid-content.

If a safety factor of 2 is to be used in the design, because the value of biological solids retention time, θ_c for design of anaerobic treatment generally range from 2 to 10 times the minimum biological solids retention time value, θ_c^m, therefore $\theta_c = 2 \times \theta_c^m = 8$ days. The anaerobic process is without recycling, so the biological solids retention time is the same as hydraulics retention time. The minimum hydraulics retention time $\theta = \theta_c = 8$ days. The maximum specific substrate utilization rate value $(k)_T$, and the total saturation constant value (Kc) are determined from equation (20) and equation (21).

$$(k)_T = (6.67 \text{ day}^{-1}).10^{-0.015(35-45.3)} = 9.5 \text{ day}^{-1}$$

$$(Kc)_T = (2224 \text{ mg COD/l}).10^{0.046(35-45.3)}$$
$$= 744.7 \text{ mg/l}$$

Then the soluble effluent substrate concentration $(Se)_{overall}$ is determined from equation (15).

$$(Se)_{overall} = \frac{1 + 0.015x20}{20(0.040x9.5 - 0.015) - 1} x744.7 \text{ mg/l}$$
$$= 153.7 \text{ mg/l}$$

The required anaerobic tank volume is Va, based on the hydraulic retention time $\theta = 8$ days.

$$Va = Q \times \theta = 211.87 \times 8 \text{ m}^3$$
$$= 16{,}950 \text{ m}^3 \approx 17{,}000 \text{ m}^3$$

The existing anaerobic tank volume at PT. Sari Husada is 650 m^3, which has a 3.08 days hydraulics retention time less than 8 days (the minimum hydraulics retention time). The affect of temperature and pH values on the anaerobic process is given in Table 4 and Figure 7, where the process is indicated by COD removal (efficiency).

From the Figure 7, the maximum COD removal (efficiency) is 70.13 % when the pH is 6.75, the minimum value is 30.68 % when the pH is 7.42, and the average value is 54.86 %. For more than 60 % COD removal obtained on 6.3 to 6.83 pH, for the range 50% to 60 % is obtained on 6.8 to 7.42 and 6.17 to 6.3 pH. The COD removal less than 40 % is obtained on pH is more than 7.42 and less than 6.17. According to Nicol, R. and Privot, C. in The Anaerobic Treatment A Grown-up Technology (1986) that the stability in the anaerobic process in the range 7 ± 0.2 of pH.

Table 4: The affect of temperature and pH values on the process efficiency

Daynumber	Temperature (° C)	pH	Efficiency (%) COD removal
1	46.83	8.00	58.77
2	45.67	7.42	59.36
3	45.00	7.42	30.68
4	45.00	7.33	52.94
5	44.33	7.00	48.66
6	45.50	7.17	56.03
7	46.00	9.33	63.84
8	46.33	6.67	67.87
9	45.83	7.42	54.63
10	46.17	6.67	59.79
11	46.50	6.38	39.69
12	46.67	6.17	34.71
13	45.67	6.67	58.65
14	46.00	6.50	62.73
15	46.17	6.50	39.35
16	43.67	8.00	39.35
17	45.83	7.83	59.52
18	44.33	6.58	47.32
19	42.17	6.75	60.83
20	45.67	6.58	54.97
21	45.50	6.17	57.05
22	45.33	7.42	59.23
23	43.17	6.67	58.69
24	43.67	7.58	39.56
25	46.17	6.83	61.45
26	47.50	6.50	64.91
27	45.83	6.33	65.11
28	46.00	6.75	70.13
29	43.00	6.58	61.39
30	44.33	5.67	58.70
Total	1359.83	208.88	1645.94
Average	45.33	6.96	54.86

The efficiency of the anaerobic process is low, it is more less then which given from the literature which are presented in Table 5.

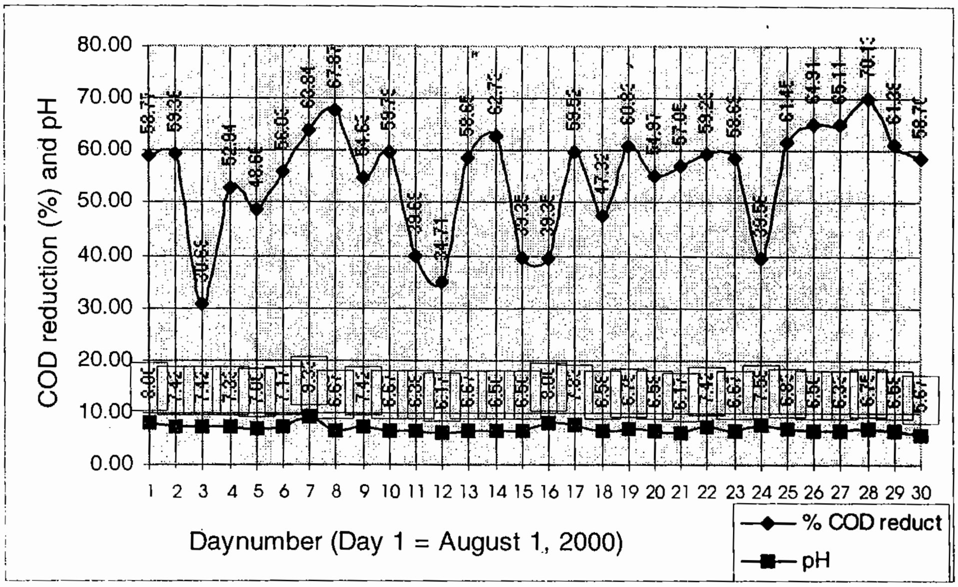

Figure 7. Procentage of COD removal and pH values for a month.

Table 5. Examples of Industrial Uses of Anaerobic Reactors

Example No.	Type of Wastewater	Waste Conc.		Deten. time	Temperature	Efficiency
		mg/l	Param.	(days)	° C	(%)
1	Rum Distillery a)	65,000	COD	16.7	36	78.5
2	Rum Distillery b)	65,000	COD	5.6	36	72
3	Wine Distillery	22,000	COD	6.9	33	97.3
4	Pomace Stillage	13,740	COD	10	35	73
5	Pear Waste	60,000	COD	3	35	91

Source: Grady, C. P. L., Jr. and Lim, H. C. (1980).

From the Table 5, that the Industrial uses of anaerobic reactors show the removal abtained up to 70 % to 90 %. These are more higher than PT. Sari Husada efficiency which obtain 54.86 % the average removal.

CONCLUSIONS

1. The anaerobic process on high temperature, that is 45.33° C so it is required the shorter minimum biological solids retention time, θ_c^m , e.i. 4 days.
2. The anaerobic process is influenced by pH value, the 6.75 of pH gives the maximum of COD removal (70.13 %), and the 7.42 of pH gives the minimum of COD removal (30.68 %). The average removal is 54.86 %. In otherhand the range of pH optimum is 6.3 to 6.83 gives the greater or same as 60 % COD removal, whereas the Industrial uses of anaerobic reactors show the removal abtained up to 70 % to 90 %.
3. The anaerobic tank of PT. Sari Husada has a low efficiency, caused by the shorter hydraulics retention time which is only 3.1 days, in fact the minimum is 8 days. The other factor are high temperature which more than 35° C and alkalinity or pH range which more fluctuative.

SUGGESTION

To increase the efficiency may be obtained by some ways:

1. By lengthen retention time to 8 days minimum can be reached by increasing the anaerobic tank volume to 17,000 m^3.
2. By descending the wastewater temperature at the anaerobic tank to the range 25° to 35° C or by controlling the pH value to the range 6.8 to 7.2.

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